Exploring applications for MAPS outside the collider domain

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Motivation & outline

- Maps are used as particle detectors in big colider experiments (ATLAS, ALICE, CBM, BELLE)
- Because C4Pi is involved in big colider projects:
  - Know-how & Technology R&D
  - Reusability of elements
  - Sharing the silicon => possible to submit small prototypes
- Smaller projects could also benefit from having a custom MAPS detectors

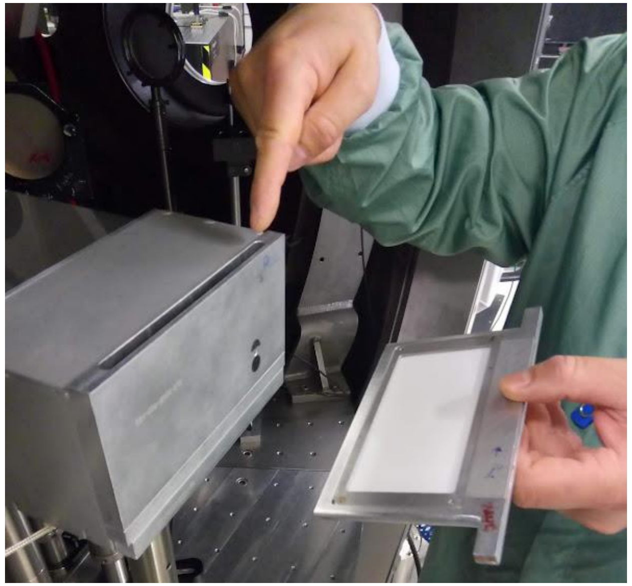
OUTLINE

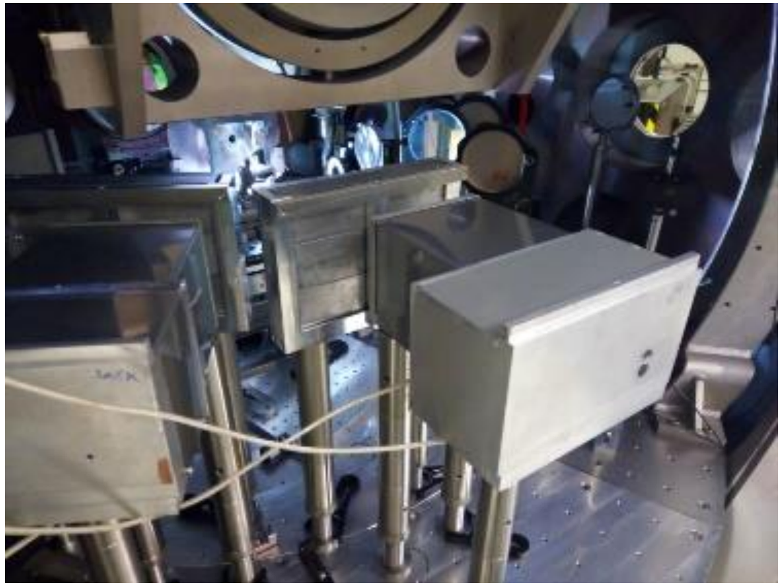
- Monitoring the outcome of laser-plasma acceleration
- Ion detection
- Molecular neuro imaging
- Low energy X-ray spectroscopy
- Future advancements?

Monitoring the outcome of laser-plasma acceleration

- Goal : Replace Imaging Plate in a Thomson parabola spectrometer
  - Detection of protons – **few MeV** to 100 MeV
- Large area detector needed => several cm^2
- EM fields in the range of MV/m => EM shielding !!

IN2P3 master project ALP- Ions with LP2I Bordeaux

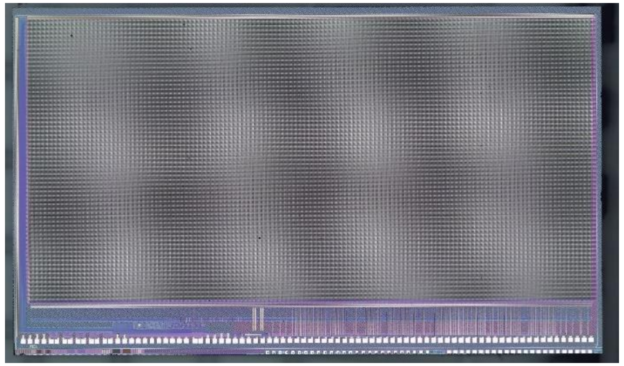


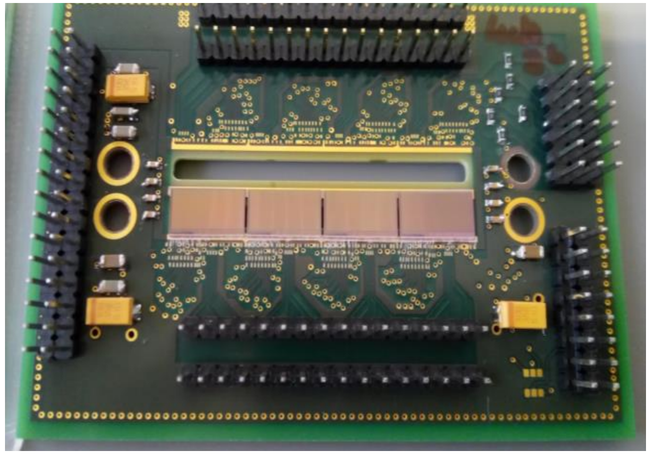


Monitoring the outcome of laser-plasma acceleration

Monolithic Imager

- Matrix of 256x512 pixels
- 5 x 10 mm active area
- Pixel size 20x20 µm
- Rolling/global shutter
- Analog readout with programmable num. of outputs (32/16/8/4)
- Multi-chip detectors possible





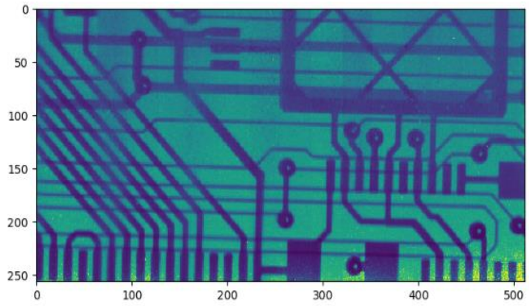
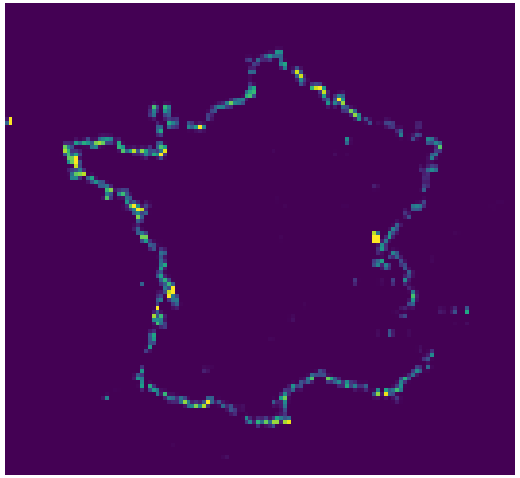
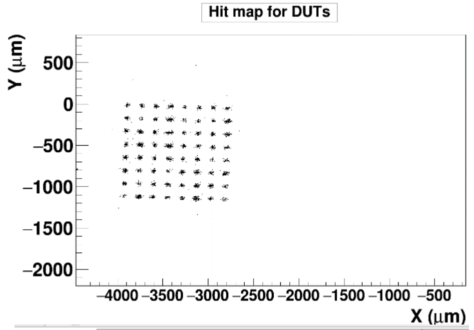
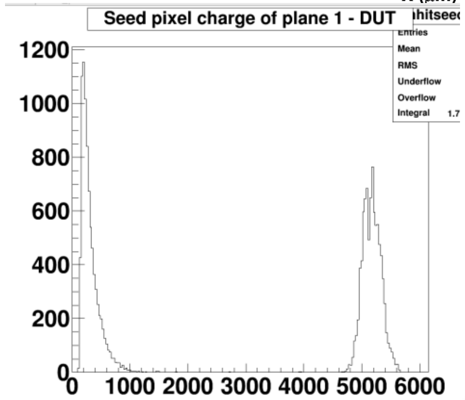


Image of a flex PCB taken with MI
Irradiated with an Cu X-ray tube

Measurements at AIFIRA 3 MeV protons







Monitoring the outcome of laser-plasma acceleration

Next steps in this project:

- Next version of Monolithic Imager with bigger input diode => smaller gain for low energy protons.

- Tests of shielding at LULI with the current setup (shielded cables + box)=> July 2023
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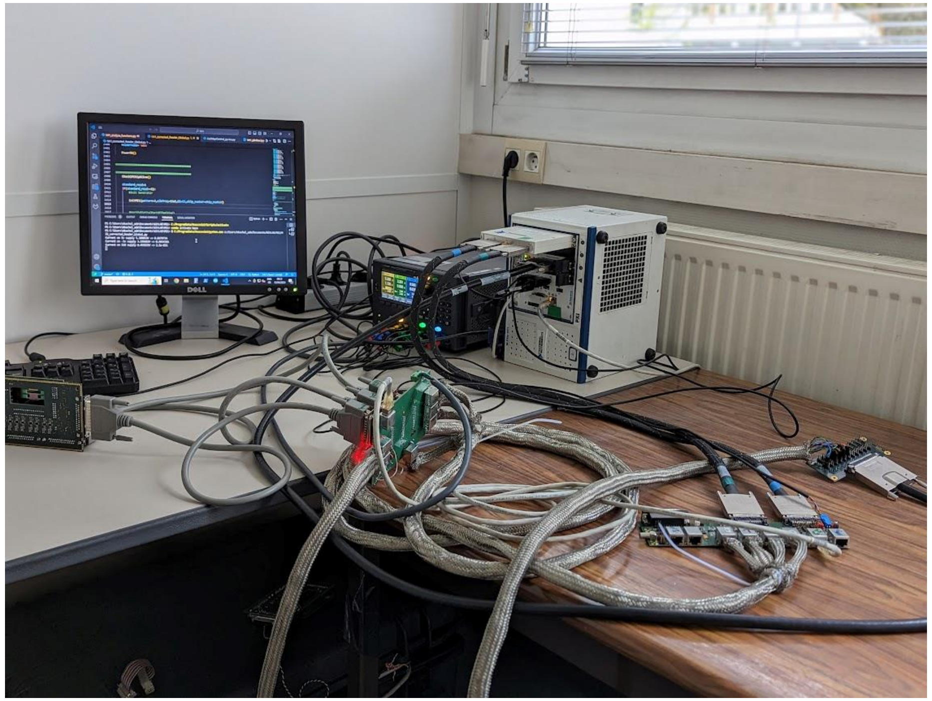
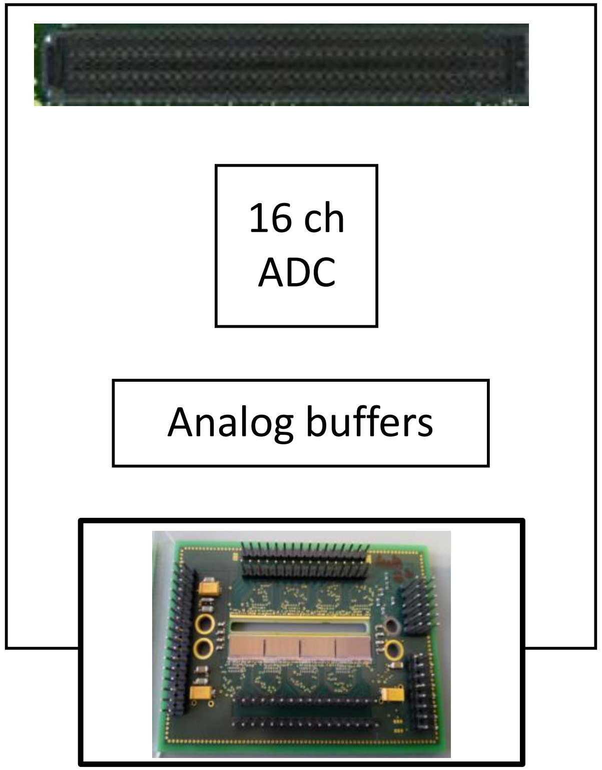
- New, compact readout in developement => see next slide

New readout

Current setup:
NI PXI with digital + ADC cards + cables..



NI SbRIO 9609 + Custom ADC board



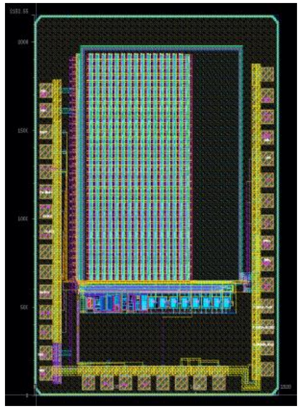
- Size ~ 10x10 cm – plug in board ~10cm x 15 cm?
- Shielded box + fiber output from the => EMP
- Cooling needed => Heat will be a problem (vacuum)

Ion identification – TIIMM project

Tracking | **Identification**

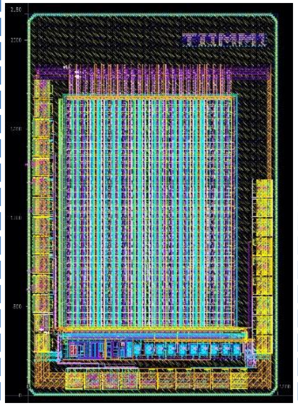
TIIMM target = **Precision tracking** $\sigma_{pos.} \leq 10\ \mu m$ + **Low material budget** $<< \%\ X_0$ + **Energy loss measurement** $1\text{-}10^3$ MIPs

- First submission: preliminary prototype (TIIMM0) submitted in March 2020.
- Second submission: TIIMM0/TIIMM1/TIIMM1A/TIIMM1B prototypes received in August 2022



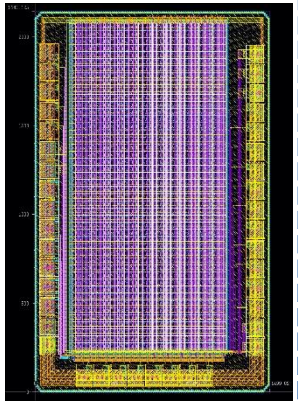
TIIMM0 (second submission)
Chip area: 2.2 mm * 1.5 mm
Matrix: 32 (rows) * 16 (col)
Pixel pitch: 40 µm×40 µm

Corrected from the first submission



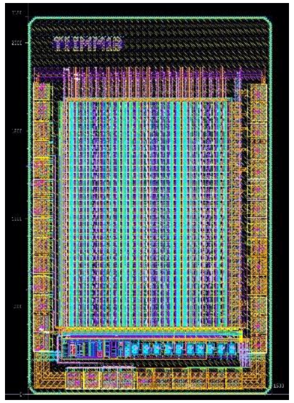
TIIMM1 sensor
Chip area: 2.2 mm * 1.5 mm
Matrix: 32 (rows) * 24 (col)
Pixel pitch: 41.2 µm×40 µm

New front-end



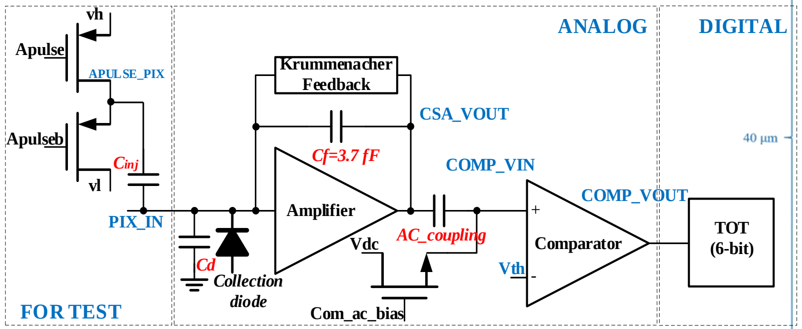
TIIMM1A sensor
Chip area: 2.2 mm * 1.5 mm
Matrix: 46 (rows) * 32 (col)

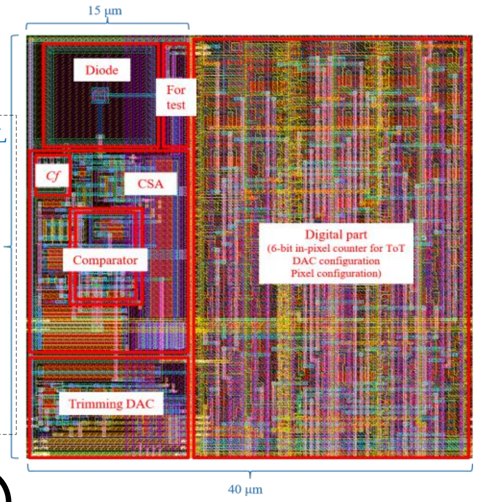
New front end
Analog part study only



TIIMM1B sensor
Chip area: 2.2 mm * 1.5 mm
Matrix: 32 (rows) * 24 (col)
Pixel pitch: 41.2 µm×40 µm

New front-end enhanced

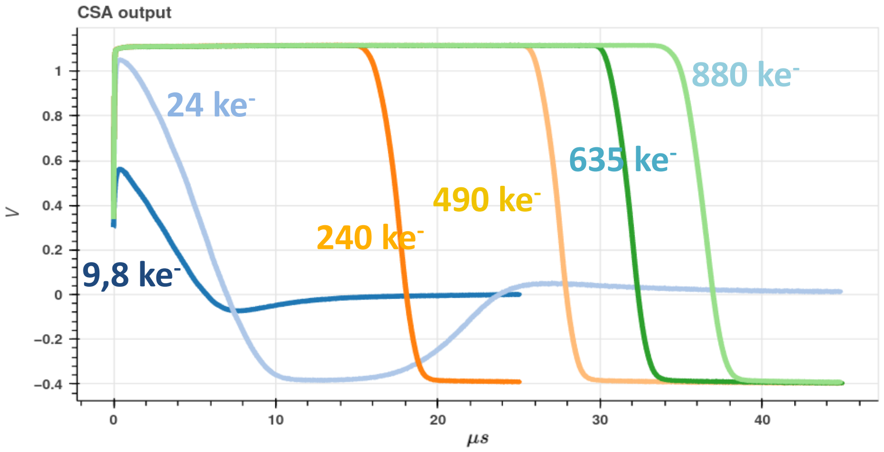


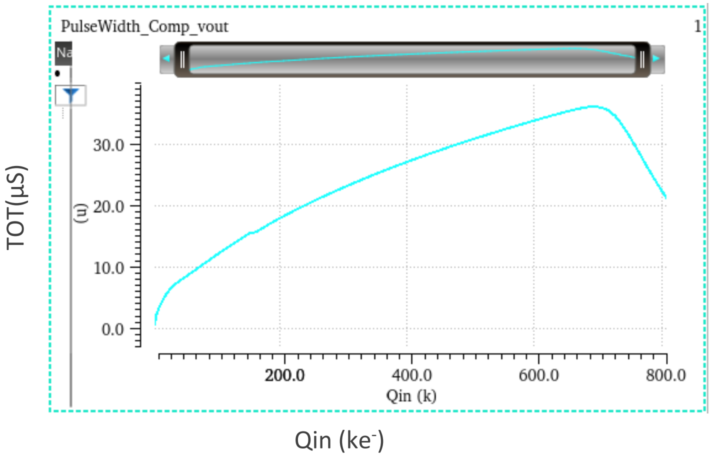


- Krummenacher feedback
- AC coupled comparator
- 6-bit TOT

Ion identification – laser measurements

Cadence Simulations

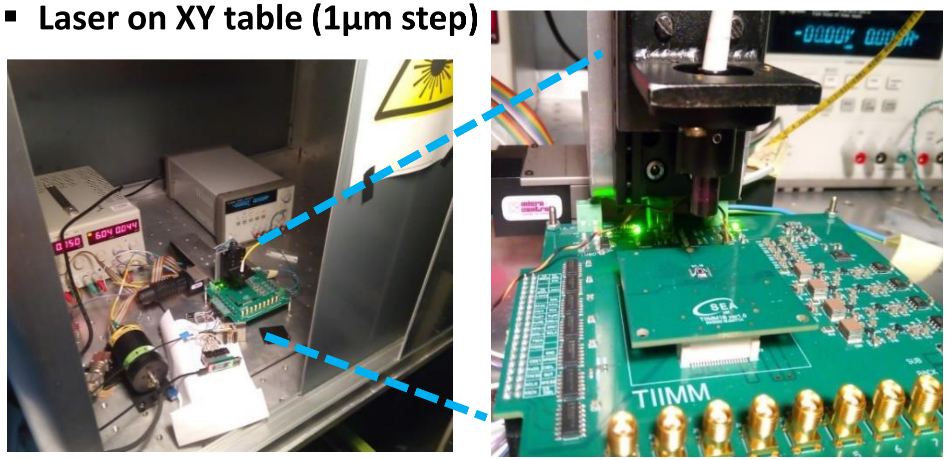


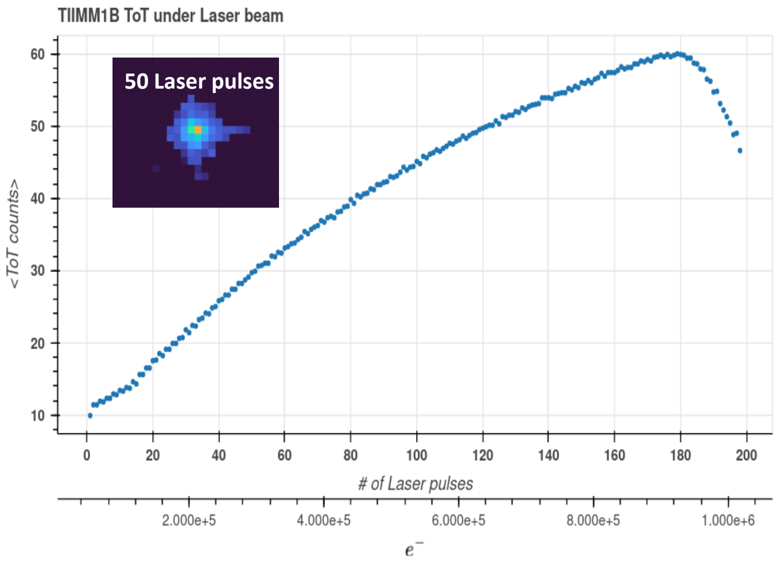


Next steps:
- New readout compleated
- Tests at Cyrce (p. 26 MeV)
- Ion beam tests

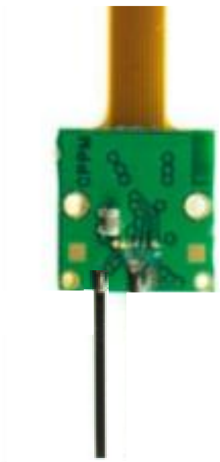
Laser measurements

- Laser wavelength : 1061 nm
- Laser on XY table (1µm step)





Molecular imaging – MAPSSIC project



1. Sensitive probe

2x IMIC sensors

2. Backpack

- Microcontroller
- Power supply
- RF antenna

Microcontroller STM32

- **2022**→ Sensor Production
- **2023**→ Characterization /MC studies
- **2024**→ Biological validation
- **2025**→ Behavioural applications

Features:

Sensitive to **short range β^+**
Record **kinetic** of **radiotracers**
Wireless probe
Autonomy to the rat

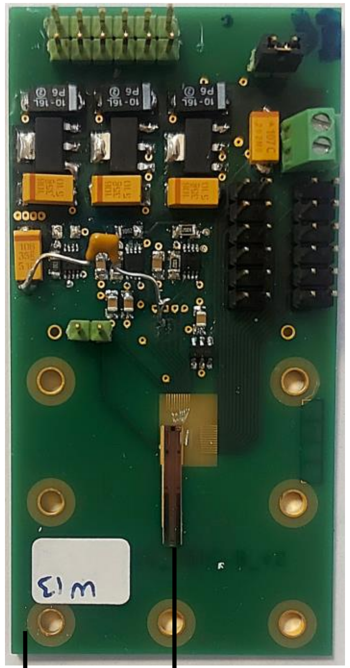
Constraints:

Gamma transparency
Light: **< 10% of rat weight**
Biocompatible
Low power consumption

From: Samir El ketara - IJCLab

MAPSSIC current developments

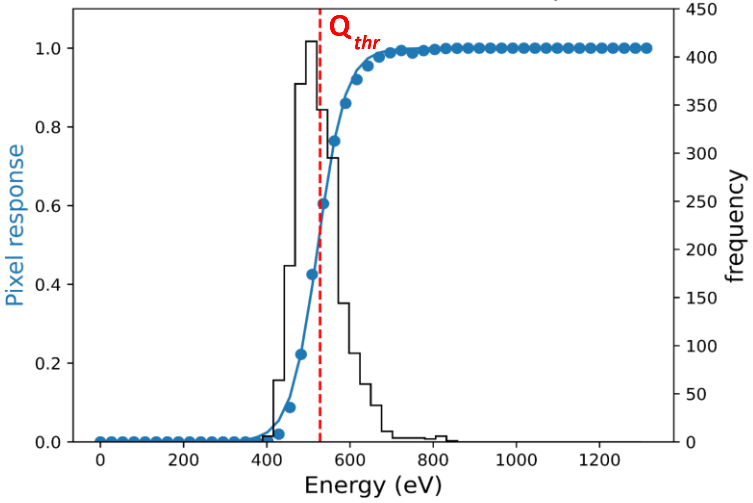
Sensor validation



IMIC sensor

Testing PCB

→ Min. threshold with internal injection



Understand the sensor's characteristics

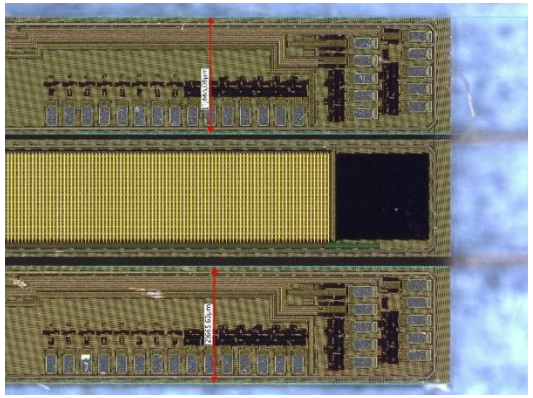
Set nominal parameters

- Charge injections
- Sealed sources
  - beta: ^{204}Tl, ^{22}Na
  - X ray: ^{55}Fe

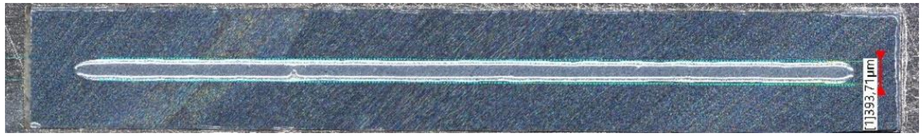
From: Samir El ketara - IJCLab

2xSensor detector construction

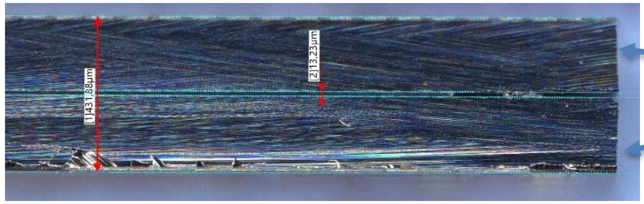
Dicing sensors



Apply glue

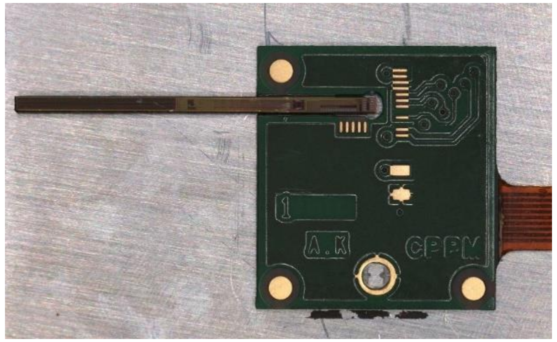


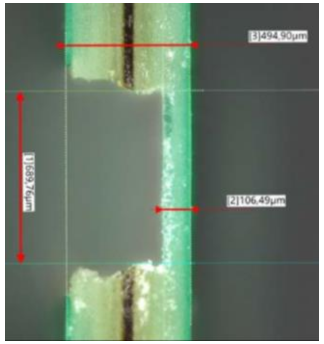
Assembly



sensors

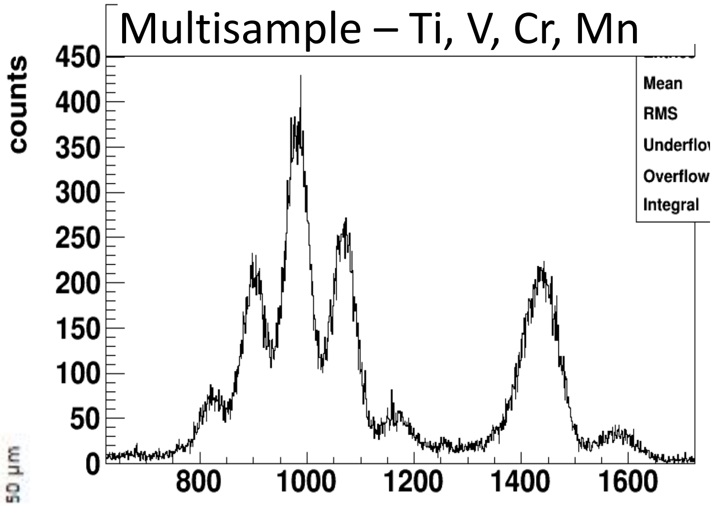
Mount the Sensor on the carrier PCB



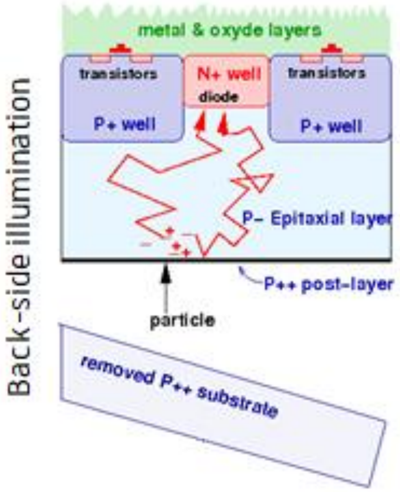


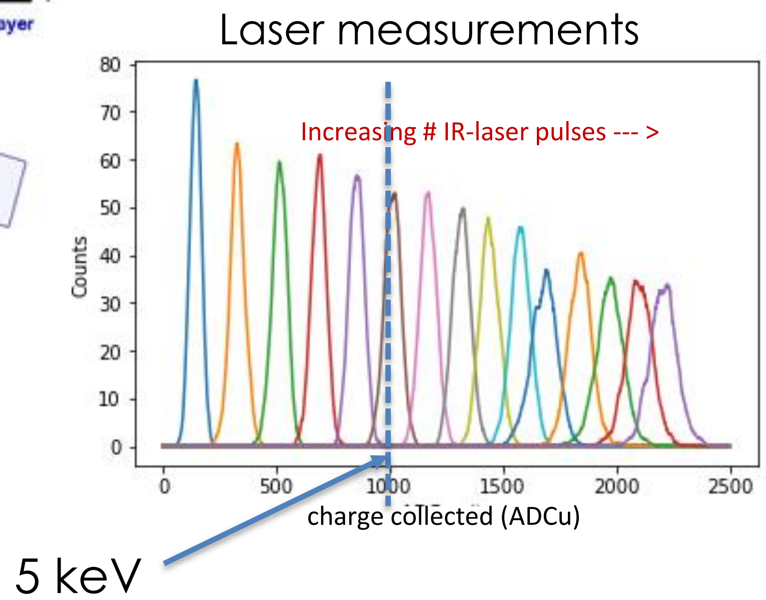
Low energy spectroscopy – using Monolithic Imager

- **First tests done at the lab**
  - Readout noise below 20 e- rms
  - Energy resolution for the Cr line (5.4 keV) is 325 eV (@ room temp)



- **Make the detector sensitive to low energies**
  - Front side illumination => oxide + metals
    - 99% of 1keV X-rays stopped in 10µm of silicon oxide
  - Back side illumination:
    - Thin down to epitaxial later (50µm)
    - Ion implantation + laser annealing (entry window - tens of nm)





- **Low energy applications:**
  - Sub keV X-ray measurements at Synchrotron facilities (SOLEIL,..)
  - Low energy Beta detection (tritium)

Future advancements

- Sensors technology
  - Different thickness of the epi layer – thinner for higher energies, thicker for efficiency

- Analog sensors readout problem
  - Stay analog - develop a compact readout solution for multichip detectors
  - Go digital - Develop an on-chip ADC (12 bit, 20 MS/s)

- Digital sensors
  - Start of the TIIX project (IPHC and IP2I Lyon)
    - Combine the TIIMM analog front-end with the readout from OBELIX (Optimized BELle II pIXel)
    - Time stamping 25-100 ns

Summary

- Maps are well suited for projects outside of colider domain
- System on chip – detector + analog + digital on chip

Project name	Decription	Particles detected	Challenge
ALPion	Laser plasma accelleration	Protons few MeV-100 MeV	Shielding Large amplitude
TIIMM / TIIX	Ion identification	Ions, ..	High dynamic range
MAPSSIC	Molecular imaging	β^+ positrons	Low power
Monolithic imager	Low energy spectroscopy	Low energy X-rays & β	Low noise

Merci pour votre attention